Effect of roasting on ruminal degradation, intestinal digestibility and absorbable amino acid profile of cottonseed and soybean oilcake meals

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The effect of heat processing on ruminal degradation, intestinal digestibility (UDP-D) and absorbable amino acid (AA) profile of cottonseed oilcake (CSOC) and soybean oilcake (SBOC) was calculated. CSOC and SBOC were roasted in a drum roaster at six temperature settings and five time intervals resulting in 30 treatments per feedstuff. Percentage acid detergent insoluble nitrogen (% ADIN) was used as a screening test. Ruminal protein degradation and UDP-D were measured with the *in situ* polyester and mobile bag techniques (MBT), respectively. Temperature and time altered ($P < 0.05$) crude protein (CP) disappearance from the rumen and total tract, as well as UDP-D. The % ADIN and the theoretical amount of AA available increased, whereas effective ruminal protein degradability decreased with temperature and time. The relationship between total N disappearance and % ADIN ($R^2 = 0.99$) for CSOC was non-linear ($P < 0.05$); for SBOC it was linear ($P < 0.05$) ($R^2 = 0.85$). The relationship between UDP-D and % ADIN ($R^2 = 0.99$) for CSOC was non-linear ($P < 0.05$); for SBOC it was linear ($P < 0.05$) ($R^2 = 0.86$). Heat processing decreased ($P < 0.05$) Lys in both CSOC and SBOC. The AA Thr, Pro and Gly in CSOC and Thr, Val, Leu, His, Asp, Gly and Ala in SBOC, were more ($P < 0.05$) resistant to rumen degradation; more Thr and Lys ($P < 0.05$) were absorbable in both CSOC and SBOC, when compared to the control. CSOC and SBOC should be treated at 150 °C/40 min and 130 °C/45 min respectively.

Die invloed van hitteprosessering op rumenproteïendegradeerbaarheid, nie-degradeerbare proteïenverteerbaarheid (UDP-V) en absorbeerbare aminosuurprofiel (AS) van sowel katoensaad- (KSOK) as soja-oliekoek (SOK) is bepaal. KSOK en SOK is in 'n dromrooster gerooster by ses temperature met vyf tydintervalle. Persentasie suuronoplosbare stikstof (% ADIN) is as 'n siftingstoets gebruik. Die *in situ* poliëster en mobiele sakkie-tegnieke (MBT) is gebruik om die effektiewe rumenproteïendegradeerbaarheid en UDP-V, respektiewelik, te bepaal. Verskille ($P < 0.05$) is verkry in die ru-proteïen verdwyning uit die rumen en totale spysverteringskanaal, asook in die UDP-V. Die % ADIN en die teoretiese hoeveelheid AS beskikbaar het toegeneem, terwyl die effektiewe rumen-proteïendegradeerbaarheid met temperatuur en tyd afgeneem het. Die verwantskap tussen totale N verdwyning en % ADIN ($R^2 = 0.99$) vir KSOK was nie-liniêr ($P < 0.05$) en liniêr ($P < 0.05$) ($R^2 = 0.85$) vir SOK. Die verwantskap tussen UDP-V en % ADIN ($R^2 = 0.99$) vir KSOK was nie-liniêr ($P < 0.05$) en liniêr ($P < 0.05$) ($R^2 = 0.86$) vir SOK. Hitteprosessering het Lis in sowel KSOK as SOK verlaag ($P < 0.05$). Die AA Tre, Pro en Gli in KSOK en Tre, Val, Leu, His, Asp, Gli en Ala in SOK was meer ($P < 0.05$) weerstandbiedend teen rumendegradering, teenoor Tre en Lis wat meer ($P < 0.05$) absorbeerbaar was in sowel KSOK as SOK, in vergelyking met die kontrole. Daar word aanbeveel dat KSOK en SOK teen respektiewelik 150 °C/40 min en 130 °C/45 min behandel word.

Keywords: Dairy cows, heat processing, amino acid flow, digestion, cottonseed oilcake, soybean oilcake.

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Introduction

Feeding protein with a low degradability to dairy cows improves milk production because such protein is not degraded in the rumen, allowing a larger supply of amino acids (AA) to pass through the intestine (Kung & Huber, 1983). Moderate heat processing is expected to decrease rumen protein degradability and increase intestinal availability of protein (Merchen, 1990); thereby offering a means of accomodating the increased use of highly degradable protein sources. The inclusion of CSOC and SBOC, which fall in the same degradation rate category as sunflower oilcake, in dairy diets is limited (Erasmus *et al.*, 1994), but can be increased if the ruminal degradation of their CP is reduced by heat treatment (Cros *et al.*, 1992; Schroeder *et al.*, 1995).

Heat processing reduces ruminal degradation of SBOC (Faldet *et al.*, 1991) and solubility of CSOC (Craig & Broderick, 1981). Faldet *et al.* (1992b) obtained the fastest heifer growth when treating full-fat soybeans at 146 °C for 30 min.

Temperature and heating times are critical for optimal ruminal escape (Stern *et al.*, 1985). The purpose of our study was therefore to quantify 'optimal' roasting conditions for CSOC and SBOC.

Materials and methods

Processing phase

CSOC and SBOC were roasted in an electric drum roaster (± 45 *l*) which rotated at 23 r.p.m. and used a gas flame as energy source. Commercial CSOC and SBOC (± 1.5 kg) were processed at six temperature settings (inside the oilcake) ranging from 110 °C to 210 °C in increments of 20 °C and with five time intervals, namely, 10, 30, 60, 90 and 120 minutes per setting. After roasting, processed products were cooled by an electric fan underneath the drum.

Only 16 CSOC and 17 SBOC samples remained after processing, because the other samples were either burnt or ashed. Owing to the cost involved, not all samples could be included in the *in situ* study and therefore a limited number were selected on the basis of a % ADIN screening, as described under the next heading.

Screening procedure

Various researchers have used % ADIN to determine heat damage in plant protein sources (Faldet *et al.*, 1991; Faldet *et al.*, 1992a; Reddy *et al.*, 1993). Results of Webster *et al.* (1986) have shown that the true absorption of N from the undegradable protein (UDP) fraction of feeds is closely but inversely related to the proportion of N which is insoluble in acid detergent. The maximum AA disappeared in the SI of sheep when SBOC was heated so that 12 to 15% of total N was in the form of ADIN (Demjanec *et al.*, 1995). Accordingly, we selected five processed samples from each protein source closer to this range for evaluation in the *in situ* phase. The method of Goering & Van Soest (1970) was used in this study.

Owing to lysine being the amino acid most vulnerable to heat damage (Anderson & Quicke, 1984, Faldet *et al.*, 1992a) the selected samples and controls were also analysed for percentage available lysine (AL) using the fluoro-2,4-dinitrobenzene (FDNB) method of Carpenter (1960), as revised by Booth (1971).

In situ phase

Animals and diet

Three lactating dairy cows, equipped with rumen and duodenal cannulae, received a lucerne-based total mixed high concentrate diet (15.6% CP, 10.5 MJ ME/kg, 33.5% NDF) *ad libitum*.

Table 1 Percentage acid detergent insoluble nitrogen (% ADIN) and percentage available lysine (% AL) in the control and heat processed cottonseed oilcake (CSOC) and soyabean oilcake (SBOC)

Feedstuff	% ADIN	% AL	% DM
Control CSOC[1]	2.68	1.26	94.32
130/60[2]	4.17	0.54	99.08
130/90	6.20	0.43	99.11
150/30	9.51	0.67	99.19
150/40[3]	11.68	0.26	99.00
150/60	34.87	0.35	99.00
Control SBOC[1]	1.37	1.88	90.76
130/30	2.13	1.71	98.72
130/45[3]	6.81	1.60	98.58
130/60	15.93	1.12	99.14
130/90	33.29	0.54	99.18
150/30	23.95	0.71	99.20

[1] Control = not roasted
[2] CSOC processed at 130 °C for 60 minutes
[3] These treatments were included after observing the vast difference between feedstuffs roasted for 30 and 60 minutes

In situ protein degradation

The *in situ* polyester bag technique (14 × 9 cm; 53 μm) as described by Erasmus *et al.* (1988) was used to determine the protein degradation. Two bags per test sample were incubated in each of the three cows during each incubation period of 0, 2, 4, 8, 16, 24, 30, 36, 42, 48 and 60 h, using the complete exchange method. After incubation, the bags were rinsed under running water and then washed in a washing machine (cold water) for 10 min. Following drying (55 °C/48 h), the contents were removed and subjected to Macro-Kjeldahl N analyses and DM (AOAC, 1984). The degradation rate was fitted to the equation as suggested by Ørskov & McDonald (1979):

$$p = a + b(1 - e^{-ct}) \qquad 1)$$

The non-linear parameters a, b and c were estimated by an iterative least-squares procedure (GENSTAT, 1990). By introducing a constant for fractional outflow rate, k, the effective protein degradation (P) (Ørskov & McDonald, 1979) was calculated as:

$$P = a + \frac{bc}{c + k} \qquad 2)$$

Fractional outflow rates of 0.02/h, 0.05/h and 0.08/h were used in the calculations, as rates can vary from 0.02/h for animals at maintenance to 0.08/h for high-producing dairy cows (ARC, 1984).

Mobile bag technique

The bags (3.5 × 5 cm, 53 μm) used in the mobile bag technique (MBT) to determine UDP-D were made according to the recommendations of Kirkpatrick & Kennelly (1985). Twelve mobile bags per cow per sample were filled with ± 1 g UDP test material and two empty bags per cow were included

Table 2 Non-linear parameters[1] a, b and c estimated by an iterative least-square procedure

	Parameters						
Feedstuff	a	SE(a)*	b	SE(b)	c	SE(c)	R^2**
Control CSOC	62.0	2.0	33.7	5.8	0.042	0.019	0.95
130/60	56.8	0.8	17.2	4.7	0.023	0.012	0.93
130/90	51.5	0.8	31.0	2.5	0.008	0.008	0.90
150/30	46.0	1.2	17.0	3.0	0.035	0.016	0.92
150/40	42.4	0.5	11.9	0.7	0.085	0.013	0.98
150/60	41.3	0.8	7.6	0.9	0.103	0.030	0.90
Control SBOC	29.7	2.0	71.2	2.4	0.127	0.011	0.99
130/30	33.6	0.8	50.8	10.4	0.015	0.005	0.99
130/45	29.2	1.6	20.9	2.6	0.053	0.019	0.91
130/60	29.1	5.4	20.8	4.1	0.055	0.036	0.78
130/90	27.6	0.5	11.9	1.2	0.037	0.010	0.97
150/30	31.6	0.9	28.4	3.9	0.035	0.001	0.98

[1] $P = a + b(1-e^{-ct})$ (Ørskov & McDonald, 1979)
* Standard error
** Adjusted R^2 values

Table 3 Effective ruminal protein degradation of control and heat processed cottonseed oilcake (CSOC) and soyabean oilcake (SBOC) calculated at three fractional outflow rates using equation 2, where a, b, c and k are respectively the immediately soluble fraction, the potentially degradable fraction, the degradation rate and the outflow rate

	Fractional rumen outflow rate		
Feedstuff	0.02/h	0.05/h	0.08/h
Control CSOC	84.9	77.5	73.7
130/60	66.0	62.2	60.6
130/90	60.7	56.0	54.4
150/30	56.7	52.9	51.1
150/40	52.0	49.9	48.5
150/60	47.6	46.4	45.5
Control SBOC	91.2	80.7	73.3
130/30	55.5	45.4	41.7
130/45	44.3	39.9	37.5
130/60	44.2	39.8	37.4
130/90	35.4	32.7	31.4
150/30	49.7	43.5	40.3

to correct for microbial contamination (Kendall *et al*., 1991). Three bags were used to determine protein disappearance from the rumen, three to compare the AA profile of UDP with that of the original processed sample, three to determine digestibility of UDP in the small and large intestine and three to determine digestibility of the AA in the small and large intestine.

All bags (14 per feedstuff) were firstly incubated in the rumen (16 h) inside a large net bag as recommended by Erasmus *et al*., (1986). Following incubation, six bags and one blank were washed and dried as discussed to determine the post-ruminal digestibility of UDP and the AA profile. The remaining six bags and one blank were incubated in a pepsin-HCl solution (1 g pepsin per litre of 0.01 N HCl) for 3 h at 39 °C to simulate abomasal digestion (Kirkpatrick & Kennelly, 1985). After digestion, these bags were kept on ice at 4 °C and inserted randomly into the duodenum via the duodenal cannula at a rate of one bag per 20 min. On recovery in the faeces they were washed, dried and prepared for N (three bags) and AA (three bags) analyses as described previously. The three bags incubated in the rumen and the three post-ruminal bags were pooled per cow for AA analysis. For AA analysis, a Beckman 7300 Amino Acid Analyzer (Beckman Instruments Inc., Spinco Div., Palo Alto, CA.) was used. For N analysis the Macro-Kjeldahl procedure according to AOAC (1984) was followed.

Statistical analysis

The statistical analysis was by least squares analysis of a completely randomized design. The basic model was $Y_{ij} = \mu + T_i + l_{ij}$, where Y_{ij} = the response; μ = overall mean; T_i = mean effect of treatment i; and l_{ij} = random residual (Harvey, 1988). Correlations were calculated with the Quattro computer program (Quattro, 1991) and GENSTAT (1990) was used for determining the effective protein degradability.

Results and discussion

The results of the chemical analysis (% ADIN, % AL and % DM) are presented in Table 1. ADIN increased dramatically in both protein sources with increases in either temperature or time, which agrees with data reported by McNiven *et al*. (1994). ADIN ranged between 2.68% for the control CSOC to 34.87% for the 150 °C/60 min treatment, whereas it ranged between 1.37% for the control SBOC to 33.29% for the 130 °C/90 min treatment. When the two protein sources were compared, it was found that much higher temperatures could be reached before heat damage occurred with CSOC. A substantial drop in AL occurred in both sources with increases in either temperature or time and both lost similar amounts of AL at specific temperatures and times. A drop in AL with increasing temperature and time was also detected in a study by Faldet *et al*. (1992a).

Table 4 Crude protein (CP) disappearance from polyester bags and digestibility of rumen-undegraded dietary protein (UDP) from control and heat processed cottonseed oilcake (CSOC) and soyabean oilcake (SBOC) together with % ADIN values

	CP disappearance (%) from				
Feedstuff	Rumen[1]	Small intestine[2]	Total tract[3]	Digestibility UDP[4]	% ADIN
Control CSOC	63.9[a]	32.6[a]	96.5[a]	91.5[a]	2.68
130/60	45.0[b]	50.0[b]	95.0[a]	92.1[a]	4.17
130/90	44.9[b]	50.8[b]	95.7[a]	92.7[a]	6.20
150/30	39.5[c]	55.9[c]	95.4[a]	91.9[a]	9.51
150/40	37.4[d]	56.4[c]	93.8[a]	90.8[a]	11.68
150/60	31.7[e]	37.1[d]	68.8[b]	53.0[b]	34.87
Control SBOC	57.8[a]	37.0[a]	94.8[a]	94.1[ac]	1.37
130/30	31.0[b]	66.0[b]	97.0[a]	96.8[a]	2.13
130/45	26.9[bd]	69.0[b]	95.9[a]	96.3[a]	6.81
130/60	25.7[bd]	67.4[b]	93.1[a]	90.5[c]	15.93
130/90	23.1[cd]	51.2[c]	74.3[b]	68.1[b]	33.29
150/30	23.2[cd]	52.3[c]	75.5[b]	68.2[b]	23.95

[a,b,c,d,e]Means in the same column without a common letter in the superscripts differ ($P < 0.05$)

1 Calculated as [(Initial) – (residue remaining after 16 h of rumen incubation)]/[initial] × 100 = % of rumen-degraded dietary protein (RDP in %)

2 Calculated as [Initial-RDP – residue after 16 h in the rumen plus intestinal incubation]/[initial] × 100

3 Sum of rumen plus intestinal disappearance

4 Calculated as [(UDP) – (residue after rumen plus intestinal incubation)]/UDP

UDP calculated as UDP = (100 – RDP)

Table 5 Total essential amino acid (TEAA) profiles of the original feedstuff (O),[1] the residue remaining in the polyester bags after 16 h of rumen incubation (R)[1] and absorbable amino acid profile of the rumen undegraded dietary protein (A)[1] for control and heat processed cottonseed oilcake (g/100g AA)

Treatment	Thr	Val	Iso	Leu	Phe	His	Lys	Arg	Met	TEAA
O										
Control	3.77^{a}	4.77^{a}	3.42^{a}	6.20^{a}	5.78^{a}	2.76^{a}	4.52^{a}	12.23^{a}	1.51^{a}	44.96^{a}
130/60	4.29^{bc}	4.86^{a}	3.43^{a}	6.29^{a}	5.43^{a}	2.86^{a}	2.86^{bc}	11.72^{a}	1.72^{a}	43.43^{ac}
130/90	3.95^{ac}	4.80^{a}	3.64^{a}	6.34^{a}	5.72^{a}	2.94^{a}	3.63^{ac}	11.37^{a}	3.32^{b}	45.69^{a}
150/30	4.32^{bc}	4.62^{a}	3.22^{a}	5.83^{a}	5.72^{a}	2.72^{a}	2.81^{c}	11.36^{a}	1.61^{a}	42.21^{c}
150/40	4.85^{d}	4.76^{a}	3.56^{a}	6.03^{a}	4.59^{b}	2.65^{a}	2.05^{bc}	8.79^{b}	1.86^{a}	39.14^{b}
150/60	4.60^{dc}	4.95^{a}	3.18^{a}	6.01^{a}	5.66^{a}	2.48^{a}	1.77^{b}	8.48^{b}	1.77^{a}	38.91^{b}
R										
Control	3.26^{a}	4.46^{a}	3.21^{ac}	5.94^{ac}	5.79^{a}	2.77^{a}	4.40^{a}	13.22^{a}	1.46^{ac}	44.51^{a}
130/60	3.79^{bc}	4.64^{ac}	3.30^{ac}	6.43^{a}	4.90^{bc}	2.76^{a}	2.04^{b}	11.96^{ac}	1.63^{ac}	41.42^{b}
130/90	3.74^{b}	4.69^{ac}	3.85^{ad}	6.70^{a}	5.96^{a}	2.85^{a}	2.25^{b}	11.46^{bc}	4.81^{b}	46.31^{a}
150/30	4.67^{c}	4.20^{a}	2.82^{c}	4.60^{bd}	5.58^{ac}	2.73^{a}	2.69^{b}	12.08^{ac}	1.39^{a}	40.76b
150/40	4.86^{c}	5.18^{bc}	4.07^{bd}	6.63^{a}	4.97^{bc}	2.44^{a}	1.90^{b}	7.13^{d}	2.01^{c}	39.19^{b}
150/60	5.06^{c}	4.37^{a}	2.62^{c}	4.90^{cd}	5.38^{ac}	1.53^{b}	0.83^{c}	6.30^{d}	1.57^{ac}	32.57^{c}
A										
Control	4.77^{a}	5.18^{a}	3.64^{a}	6.59^{a}	5.65^{a}	2.97^{a}	4.43^{a}	10.78^{a}	1.87^{a}	45.88^{a}
130/60	4.51^{b}	4.85^{a}	3.37^{a}	6.13^{a}	5.86^{a}	3.10^{a}	3.54^{b}	11.74^{b}	1.64^{bc}	44.71^{ac}
130/90	4.13^{bc}	4.83^{a}	3.29^{a}	5.87^{a}	5.70^{a}	2.95^{a}	2.98^{b}	11.42^{b}	1.69^{a}	42.86^{bc}
150/30	4.22^{b}	4.91^{a}	3.41^{a}	6.46^{a}	5.72^{a}	2.84^{a}	1.94^{cd}	11.13^{b}	1.81^{ac}	42.44^{bc}
150/40	4.38^{b}	4.70^{a}	3.32^{a}	6.17^{a}	5.73^{a}	2.89^{a}	2.71^{bd}	11.74^{b}	1.68^{ac}	43.32^{ac}
150/60	3.82^{c}	4.86^{a}	3.25^{a}	6.10^{a}	6.09^{a}	3.00^{a}	1.63^{c}	10.24^{b}	1.60^{ac}	40.58^{b}

$^{a, b, c, d, e}$ Means in the same column O, R or A without a common superscript differ ($P < 0.05$)

[1] Least squares means (Harvey, 1988) ($n = 3$)

When the protein degradation rate was calculated using equation 1, the immediately soluble fraction *a* dropped from 62.0% for the control CSOC to 41.3% for the 150 °C/60 min treatment and from 29.7% for the control SBOC to 27.6% for the 130 °C/90 min treatment (Table 2). There was therefore a reduction in protein solubility with temperature and time, especially for CSOC. Heat processing of protein sources such as soybeans generally decreases the amount of rapidly soluble N-fraction, the rate of degradation and the estimated extent of CP degradation, while increasing the size of the slowly degraded protein fraction (Mosimanyana & Mowat, 1992). However the size of the insoluble *b* fraction in our study decreased with temperature and time, which is in agreement with findings of Mir *et al.* (1984).

The effective protein degradation values at 0.08/h declined (using equation 2) from 73.7% to 45.5% with heat processing, and from 73.3% to 31.4% for the CSOC and SBOC respectively (Table 3). This agrees with data reported by Broderick & Craig (1980) for control (78.8%) and autoclaved CSOC (25.1%). Even though CSOC could be roasted longer at the same temperature than SBOC (90 vs. 45 min at 130 °C) to achieve similar ADIN values, the effective protein degradation rate remained higher in the case of CSOC.

The CP disappearance from polyester bags and the UDP-D are shown in Table 4. The mean retention times of the mobile bags were 13.1 h ± 3.2 h and 12.5 h ± 3.6 h for CSOC and SBOC respectively. This is in line with reported retention times of 13.72 h ± 2.05 h (Erasmus *et al.*, 1988) and 12.3 h ± 3.47 h (Schroeder *et al.*, 1995).

Compared to the control, CP disappearance from the rumen (16 h) decreased ($P < 0.05$) in both CSOC and SBOC with increased temperature and time. The CP disappearance from the rumen of the control CSOC and SBOC was slightly lower than that reported by Susmel *et al.* (1994), mainly due to the shorter ruminal incubation time of 14.3 h used in their study. Owing to the lowered rumen degradation after processing, passage of UDP to the SI was increased and N disappearance from the SI increased ($P < 0.05$). Total CP disappearance for the control SBOC of 94.8% corresponded with the value reported by Rae & Smithard (1985). As far as UDP-D was concerned, significant differences were found between the control and processed CSOC and SBOC. With the exception

Table 6 Total non-essential amino acid (TNEAA) profiles of the original feedstuff (O),[1] the residue remaining in the polyester bags after 16 h of rumen incubation (R)[1] and absorbable amino acid profile of the rumen undegraded dietary protein (A)[1] for control and heat processed cottonseed oilcake (g/100g)

Treatment	Asp	Ser	Glu	Pro	Gly	Ala	Tyr	TNEAA
O								
Control	9.71^{a}	5.69^{ab}	22.44^{a}	4.27^{a}	4.69^{a}	4.44^{ac}	3.77^{a}	55.02^{a}
130/60	9.86^{a}	6.01^{a}	23.00^{ac}	4.57^{a}	4.86^{a}	4.58^{ac}	3.71^{a}	56.58^{a}
130/90	9.53^{ab}	5.65^{ab}	22.38^{c}	4.49^{a}	4.78^{a}	4.56^{ac}	3.87^{a}	55.25^{a}
150/30	9.75^{a}	5.83^{a}	23.52^{ac}	4.62^{a}	5.03^{a}	3.92^{a}	4.00^{a}	56.67^{a}
150/40	8.53^{b}	5.72^{ab}	24.66^{bc}	5.54^{b}	6.74^{b}	5.89^{b}	3.58^{a}	60.67^{b}
150/60	10.38^{a}	5.42^{b}	24.98^{bc}	5.19^{b}	5.66^{c}	5.31^{bc}	4.01^{a}	60.94^{b}
R								
Control	10.14^{ab}	5.29^{a}	24.32^{ab}	4.05^{a}	4.33^{a}	3.74^{a}	3.61^{a}	55.49^{a}
130/60	10.93^{a}	5.47^{ab}	25.91^{a}	4.14^{a}	4.69^{ab}	3.81^{a}	3.63^{a}	58.58^{b}
130/90	9.49^{b}	5.24^{a}	22.32^{b}	4.17^{a}	4.62^{a}	4.10^{a}	3.75^{a}	53.69^{a}
150/30	9.78^{b}	5.75^{b}	24.68^{a}	4.68^{b}	5.20^{bd}	4.84^{a}	4.31^{b}	59.24^{b}
150/40	8.02^{c}	5.26^{a}	25.32^{a}	5.61^{c}	7.25^{c}	5.99^{b}	3.35^{a}	60.80^{b}
150/60	12.74^{d}	5.36^{a}	29.73^{c}	5.04^{b}	5.61^{d}	4.63^{a}	4.32^{b}	67.44^{c}
A								
Control	9.21^{a}	6.34^{ad}	19.14^{ad}	4.74^{a}	5.12^{a}	5.65^{a}	3.91^{a}	54.11^{a}
130/60	9.13^{a}	6.18^{ac}	20.92^{ac}	4.90^{a}	5.00^{bc}	5.34^{a}	3.84^{a}	55.29^{ac}
130/90	9.74^{a}	5.97^{bc}	22.64^{bc}	4.73^{a}	4.96^{ac}	5.08^{a}	4.06^{a}	57.18^{bc}
150/30	9.87^{a}	6.03^{ac}	23.09^{bce}	4.75^{a}	4.94^{ac}	5.01^{a}	3.86^{a}	57.55^{bc}
150/40	9.41^{a}	6.08^{bc}	22.64^{bc}	4.74^{b}	5.08^{ac}	5.13^{a}	3.60^{a}	56.68^{ac}
150/60	10.09^{a}	5.34^{d}	24.95^{de}	4.95^{b}	5.15^{ac}	5.18^{a}	3.75^{a}	59.42^{b}

[a, b, c, d, e] Means in the same column O, R or A without a common superscript differ ($P < 0.05$)
[1] Least squares means (Harvey, 1988) ($n = 3$)

of the 150 °C/60 min treatment for CSOC and the 130 °C/90 min and 150 °C/30 min treatment for SBOC, all other treatments were above the UDP-D limits set by the ARC (1984) and NRC (1989) of 85 and 80%, respectively. These three treatments exceeded the % ADIN norm of 12 to 15%, demonstrating the value of ADIN as an indicator of heat damage when used as a screening test. High correlations were found between UDP-D and % ADIN ($y = 90.4 + 0.61 \times ADIN - 0.05 \times (ADIN)^2$, $R^2 = 0.99$ for CSOC; $y = 99.4 - 0.99 \times ADIN$, $R^2 = 0.86$ for SBOC) and between total tract CP disappearance and % ADIN ($y = 96.6 - 0.02 \times (ADIN)^2$, $R^2 = 0.99$ for CSOC; $y = 98.9 - 0.75 \times ADIN$, $R^2 = 0.85$ for SBOC). The UDP-D of 94.1% for CSOC and 91.5% for SBOC is in agreement with data reported by Erasmus *et al.* (1994) and Masoera *et al.* (1994).

Amino acid profile

The value of a feedstuff in providing limiting essential AA (EAA) for absorption from the intestine determines to a large extent its value as a dietary protein for ruminants (Cros *et al.*, 1992). The essential and non-essential AA profile of the original feedstuff (O), the profile of the residue remaining in the polyester bags after 16 h of rumen incubation (R) and the absorbable profile of the UDP (A) are presented in Tables 5 and 6 for CSOC and in Tables 7 and 8 for SBOC.

Before incubation, heat processing invariably decreased ($P < 0.05$) the concentration of Lys in both CSOC and SBOC, which is in agreement with studies reported by Cros *et al.* (1992) and Demjanec *et al.* (1995). On the other hand Thr, Glu and Gly increased ($P < 0.05$) with heat processing of both CSOC and SBOC. In the case of CSOC, the total essential AA amount (TEAA) decreased significantly ($P < 0.05$) with heat processing.

The AA profiles of both the CSOC and SBOC controls after rumen incubation are of the same order though slightly lower than those reported by Susmel *et al.* (1994), due to the shorter incubation time. Thr, Pro and Gly in CSOC and Thr, Val, Leu, His, Asp, Gly and Ala in SBOC were significantly ($P < 0.05$) more resistant to microbial degradation than the others, which agrees with the results reported by Susmel *et al.* (1989). Phe and Lys in both CSOC and SBOC were less ($P < 0.05$) resistant. The total amount of non-essential AA (TNEAA) increased

Table 7 Total essential amino acid (TEAA) profiles of the original feedstuff (O),[1] the residue remaining in the polyester bags after 16 h of rumen incubation (R)[1] and absorbable amino acid profile of the rumen undegraded dietary protein (A)[1] for control and heat processed soybean oilcake (g/100 g AA)

Treatment	Thr	Val	Iso	Leu	Phe	His	Lys	Arg	Met	TEAA
O										
Control	4.29^{a}	5.03^{a}	4.67^{a}	8.10^{a}	5.24^{ab}	2.55^{a}	5.81^{a}	7.60^{a}	1.48^{a}	44.75^{a}
130/30	4.41^{ac}	4.97^{a}	4.63^{a}	7.21^{a}	5.21^{ab}	2.69^{bc}	4.72^{b}	7.70^{a}	1.48^{a}	44.01^{a}
130/45	4.38^{ac}	4.98^{a}	4.62^{a}	8.28^{a}	5.27^{ab}	2.77^{b}	4.07^{b}	7.68^{a}	1.55^{b}	43.59^{a}
130/60	4.60^{bc}	5.00^{a}	4.62^{a}	8.18^{a}	5.04^{a}	2.73^{bc}	3.18^{c}	7.58^{a}	1.53^{a}	42.46^{a}
130/90	4.78^{b}	5.04^{a}	4.76^{a}	8.38^{a}	5.29^{ab}	2.65^{ac}	2.35^{c}	7.76^{b}	1.44^{a}	41.44^{a}
150/30	4.38^{a}	4.89^{a}	4.73^{a}	8.17^{a}	5.48^{b}	2.65^{ac}	3.12^{c}	6.63^{b}	1.56^{a}	41.83^{a}
R										
Control	3.82^{a}	4.73^{a}	4.49^{a}	7.82^{ac}	5.22^{a}	2.56^{a}	5.99^{a}	8.24^{a}	1.35^{ac}	4.21^{a}
130/30	4.18^{c}	5.01^{ac}	4.60^{a}	8.42^{bc}	5.15^{ac}	2.77^{b}	4.58^{b}	8.41^{a}	1.36^{ac}	44.48^{a}
130/45	3.91^{ac}	5.51^{b}	4.80^{a}	8.98^{b}	4.92^{ac}	2.86^{b}	2.83^{c}	8.21^{a}	1.64^{ac}	43.63^{a}
130/60	4.69^{b}	5.32^{bc}	4.61^{a}	8.22^{c}	4.16^{d}	2.85^{b}	1.81^{d}	7.98^{a}	1.66^{a}	41.30^{a}
130/90	5.19^{d}	4.92^{ac}	4.70^{a}	7.97^{ac}	4.71^{c}	2.65^{a}	1.87^{d}	6.88^{b}	0.70^{b}	39.58^{a}
150/30	3.84^{a}	4.89^{a}	5.07^{a}	7.66^{a}	6.32^{b}	2.43^{c}	3.84^{b}	6.34^{c}	1.32^{c}	41.46^{a}
A										
Control	5.04^{a}	5.52^{a}	4.98^{a}	8.61^{a}	5.26^{a}	2.54^{a}	5.46^{a}	6.63^{a}	1.69^{a}	45.73^{a}
130/30	4.50^{b}	4.92^{b}	4.63^{a}	8.08^{ab}	5.23^{a}	2.64^{ab}	4.78^{ab}	7.38^{b}	1.55^{a}	43.73^{a}
130/45	4.54^{b}	4.75^{b}	4.48^{a}	8.00^{b}	5.32^{a}	2.73^{bc}	4.37^{b}	7.49^{b}	1.58^{a}	43.25^{a}
130/60	4.50^{b}	4.77^{b}	4.60^{a}	8.11^{ab}	5.51^{a}	2.66^{bc}	3.89^{b}	7.44^{b}	1.46^{a}	42.94^{a}
130/90	4.42^{b}	4.81^{b}	4.66^{a}	8.31^{ab}	5.51^{a}	2.59^{ac}	2.33^{c}	7.11^{b}	1.62^{a}	41.36^{a}
150/30	4.35^{b}	4.65^{b}	4.48^{a}	8.20^{ab}	5.48^{a}	2.73^{b}	2.81^{c}	7.07^{ab}	1.57^{a}	41.43^{a}

[a, b, c, d, c] Means in the same column O, R or A without a common superscript differ ($P < 0.05$)

[1] Least squares means (Harvey, 1988) (n = 3)

($P < 0.05$) in both CSOC and SBOC, whereas the TEAA in the CSOC decreased ($P < 0.05$). Tamminga (1979) found that Met was the AA most resistant to rumen degradation, which coincided with the findings in our study.

In both CSOC and SBOC, as far as the absorbable AA profiles were concerned, Arg and Glu were less ($P < 0.05$) absorbable when compared to the control. On the other hand, Thr and Lys were more ($P < 0.05$) absorbable in both CSOC and SBOC. The TEAA amount in CSOC was more ($P < 0.05$) absorbable and the TNEAA concentration less absorbable compared to the control. In all AA profiles the Lys concentration decreased ($P < 0.05$), which was similar to the findings of Faldet *et al.* (1992b). The highly reactive δ-amino group of lysine apparently is the main reason (Anderson & Quicke, 1984).

The importance of optimum heat processing in each processed sample is illustrated in Tables 9 and 10, in which the theoretical contribution of AA from control and heat processed CSOC and SBOC to the duodenal AA supply is calculated. This was done by using the degradability in the rumen (Table 3), the AA contents of the UDP entering the SI and the digestibility of the specific AA for each treatment. From these tables it can be seen that heat processing increased the amount available in the SI which corresponds with the findings of Nishimuta *et al.* (1974) when heat processed SBOC was fed to steers. Several studies have shown that heat treatment of SBOC can result in significant increases in milk yield when fed to high producing cows in early lactation (Stern *et al.*, 1985). The largest amount of AA theoretically available in CSOC and SBOC occurred at the 150°C/40 min and 130°C/45 min treatments respectively, which are just below the recommended norm of 12 to 15% ADIN.

Conclusions

Heat processing decreased the % AL considerably and also influenced the effective degradability of both CSOC and SBOC. Crude protein disappearance in the rumen was inversely related with N disappearance in the SI in both CSOC and SBOC. UDP-D was above the accepted norms, except when heat damage indicated by a very high % ADIN occurred. Linear relationships ($P < 0.05$) were found between ADIN and total tract CP disappearance ($R^2 = 0.95$ for CSOC;

Table 8 Total non-essential amino acid (TNEAA) profiles of the original feedstuff (O),[1] the residue remaining in the polyester bags after 16 h of rumen incubation (R)[1] and absorbable amino acid profile of the rumen undegraded dietary protein (A)[1] for control and heat processed soybean oilcake (g/100g AA)

Treatment	Asp	Ser	Glu	Pro	Gly	Tyr	Ala	TNEAA
O								
Control	11.38[a]	6.17[a]	19.43[a]	5.31[a]	4.29[a]	4.17[a]	4.50[a]	60.28[a]
130/30	11.57[ac]	6.31[a]	19.60[ab]	5.42[a]	4.34[a]	4.09[a]	4.65[a]	60.95[a]
130/45	11.66[ac]	6.35[a]	19.63[ab]	5.44[a]	4.51[ab]	4.09[a]	4.71[a]	61.39[a]
130/60	11.93[bc]	6.44[a]	20.06[ab]	5.67[a]	4.55[ab]	4.11[a]	4.78[a]	62.54[a]
130/90	12.12[b]	6.34[a]	20.48[b]	5.87[a]	4.74[b]	4.16[a]	4.85[ab]	63.59[b]
150/30	11.66[ac]	6.26[a]	19.95[ab]	5.91[a]	4.77[b]	4.42[b]	5.19[b]	63.06[b]
R								
Control	11.61[ad]	5.88[a]	21.28[ad]	5.26[a]	3.88[a]	3.92[a]	3.96[a]	60.51[a]
130/30	11.69[ac]	6.04[a]	20.23[bc]	5.23[a]	4.04[a]	3.95[a]	4.33[ab]	60.53[b]
130/45	12.14[bc]	5.98[a]	20.50[ab]	5.28[a]	4.38[b]	3.67[b]	4.42[b]	61.87[a]
130/60	12.88[c]	6.39[a]	21.14[acc]	5.55[a]	4.45[b]	3.83[ab]	4.45[b]	64.02[b]
130/90	12.76[c]	6.45[a]	21.99[dc]	5.89[a]	4.84[c]	3.79[ab]	4.69[b]	65.34[b]
150/30	11.19[d]	6.07[a]	19.90[b]	6.14[a]	4.85[c]	4.66[c]	5.72[c]	63.19[c]
A								
Control	11.13[a]	6.59[a]	16.59[a]	5.30[a]	4.82[a]	4.53[a]	3.91[a]	59.79[a]
130/30	11.55[a]	6.43[a]	19.39[bc]	5.49[a]	4.45[b]	4.15[b]	4.81[b]	61.19[ac]
130/45	11.51[a]	6.52[a]	19.49[b]	5.56[a]	4.58[ab]	4.22[b]	4.86[b]	61.49[bc]
130/60	11.50[a]	6.46[a]	19.70[b]	5.72[a]	4.55[ab]	4.23[b]	4.89[b]	61.82[bc]
130/90	12.15[b]	6.31[a]	21.01[c]	5.92[a]	4.51[b]	4.13[b]	4.61[b]	63.45[ac]
150/30	12.09[b]	6.34[a]	20.78[c]	5.84[a]	4.57[ab]	4.21[b]	4.74[b]	63.33[b]

[a, b, c, d, e] Means in the same column O, R or A without a common superscript differ ($P < 0.05$)

[1] Least squares means (Harvey, 1988) (n = 3)

R^2 = 0.85 for SBOC) and between ADIN and UDP digestibility (R^2 = 0.93 for CSOC; R^2 = 0.86 for SBOC).

Compared to the control, heat processing decreased ($P < 0.05$) Lys concentration in both CSOC and SBOC, but increased Thr, Glu and Gly. Phe and Lys in both protein sources were less ($P < 0.05$) resistant to microbial degradation in the rumen after heating. Arg and Glu were less ($P < 0.05$) absorbable than others.

When the AA profile theoretically available was calculated, the largest amount of AA occurred at the 150 °C/40 min and 130 °C/45 min treatments for CSOC and SBOC respectively. The results suggest that inclusion of these treatments in dairy cow rations could be advantageous.

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Table 9 Amount (g) of amino acid (AA) theoretically available from the test feedstuff for a 600 kg dairy cow with an intake of 23 kg per day and an inclusion level of 10%

	CSOC					
	Control	130/60	130/90	150/30	150/40	150/60
% ADIN	2.68	4.17	6.20	9.51	11.68	34.87
AA						
Asp	14.38[1]	25.49	31.32	30.62	29.97	22.27
Thr	7.45	12.08	12.42	12.97	14.00	8.53
Ser	9.89	16.52	18.44	18.52	19.43	11.88
Glu	29.96	58.94	70.34	71.93	71.90	55.14
Pro	7.39	12.87	14.87	14.52	15.16	11.04
Gly	8.00	13.33	15.12	15.22	16.16	11.50
Ala	8.82	14.20	15.51	15.37	16.31	11.58
Val	8.08	13.68	14.71	15.09	15.21	10.75
Iso	5.67	9.58	10.20	10.62	10.68	7.15
Leu	10.26	17.51	18.63	20.19	19.92	13.34
Tyr	6.12	10.54	13.09	11.75	11.64	8.34
Phe	8.83	16.53	17.95	18.10	18.31	13.41
His	4.64	8.36	9.01	8.76	9.16	6.66
Lys	6.89	9.70	9.76	5.85	7.99	3.60
Arg	16.81	31.79	36.97	34.63	37.12	22.79
Met	2.92	4.78	4.83	5.68	5.40	3.48
Total	156.10	275.90	313.18	309.81	318.34[2]	221.48

[1] 600 kg Dairy cow, 23 kg intake/day, 10% CSOC inclusion level
= 2300 g
= 2300 g (CSOC) × 0.9432 (DM, Table 1) = 2169.36 g (CSOC)
= 2169.36 g (CSOC) × 0.737 (DEGR., Table 3) = 1598.18 g (CSOC)
= 2169.36 g (CSOC) – 1595.18 g (DEGR. CSOC) = 570.54 g (Undegradable CSOC)
= 570.54 g (UDP) × 0.0262 (% Asp. in undeg. CSOC)
= 14.95g Asp × 0.9617 (% diges. of Asp.) = 14.38 g digestible Asp

[2] The largest amount of AA is theoretically available at 150 °C/30 min

Table 10 Amount (g) of amino acid (AA) theoretically available from the test feedstuff for a 600 kg dairy cow with an intake of 23 kg per day and an inclusion level of 7%

	SBOC					
	Control	130/30	130/45	130/60	130/90	150/30
% ADIN	1.37	2.13	6.81	15.93	33.29	23.95
AA						
Asp	24.46[1]	62.61	67.00	62.85	55.98	53.24
Thr	11.06	24.40	26.43	24.58	20.36	19.14
Ser	14.46	34.80	37.94	35.26	29.08	27.89
Glu	36.39	105.00	113.38	107.64	96.74	91.45
Pro	11.60	29.73	32.28	31.25	27.27	25.69
Gly	10.57	24.07	26.58	24.85	20.78	20.11
Ala	11.62	26.02	28.25	26.70	21.30	20.87
Val	12.11	26.66	27.63	26.08	22.19	20.98
Iso	10.93	25.11	26.13	25.21	21.48	19.71
Leu	18.92	43.78	46.59	44.33	38.29	36.13
Tyr	9.93	22.43	24.57	23.11	19.03	18.57
Phe	11.57	28.33	31.02	30.14	25.41	24.11
His	5.59	14.32	15.86	14.55	11.96	11.99
Lys	12.00	25.93	25.54	21.26	10.75	12.39
Arg	14.57	39.98	43.61	40.65	32.75	31.09
Met	3.70	8.40	9.14	7.95	7.49	6.93
Total	219.48	541.56	581.95[2]	546.41	460.85	440.29

[1] 600 kg Dairy cow, 23 kg intake/day, 7% SBOC inclusion = 1610 g
=1610 g (SBOC) × 0.9076 (DM, Table 1) = 1461.24 g (SBOC)
= 1461.24 g (SBOC) × 0.733 (DEGR, Table 3) = 1071.53 g (Degr. SBOC)
= 1461.24 g (SBOC) – 1071.53 g (DEGR. SBOC) = 389.71 g (Undegradable SBOC)
= 389.71 (undeg. SBOC) × 6.33/100 (% Asp. in undeg. SBOC)
= 24.67 g Asp. × 0.992 (% diges. of Asp.) = 24.46 g digestible Asp

[2] The largest amount of AA is theoretically available at 130 °C/45 min

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